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# An analytical modeling framework to evaluate converged networks through business-oriented metrics

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ABSTRACT

Nowadays, society has increasingly relied on convergent networks as an essential means for individuals, businesses, and governments. Strategies, methods, models and techniques for preventing and handling hardware or software failures as well as avoiding performance degradation are, thus, fundamental for prevailing in business. Issues such as operational costs, revenues and the respective relationship to key performance and dependability metrics are central for defining the required system infrastructure. Our work aims to provide system performance and dependability models for supporting optimization of infrastructure design, aimed at business oriented metrics. In addition, a methodology is also adopted to support both the modeling and the evaluation process. The results showed that the proposed methodology can significantly reduce the complexity of infrastructure design as well as improve the relationship between business and infrastructure aspects.



## 1. Introduction

The infrastructure required to support services of converged networks is increasingly more complex than ordinary communication networks. It takes the form of complex system interconnections through a variety of network components such as routers, switches, firewalls, communication links, and other related components.

In order to realize the design of converged networks, infrastructure metrics (e.g., availability, reliability, throughput) as well as their values should be selected, beyond the effort to achieve a design that minimizes costs and meets the selected metrics. Since converged networks are a means to helping the business meet its objectives, not formally taking business requirements into account is a major weakness. Ref. [10] explains that today's approach in meeting business requirements is to talk to business managers and ask them what the business needs in terms of availability, reliability, etc. These requirements are then expressed formally in a document called Service Level Agreement (SLA) [14], whereby the service provider makes certain guarantees that the service user can expect to be fulfilled.

This problem should be considered seriously, since hundreds of thousands of dollars in financial outlay can easily be the difference between an *ad hoc* solution and another one that formally takes business considerations into account, even for medium-sized infrastructures [10].

In the last years, some optimization techniques have been proposed for system designs (telecommunication systems, manufacturing systems and power systems) [5,7,9,11,15–17]. These systems consider reliability as an important design measure. Generally, the optimization techniques can be classified as linear programming, dynamic programming, integer programming, geometric programming, heuristic methods, genetic algorithms (GA) or a hybrid approach.

Ref. [5] proposes a decomposition-based approach to exactly solve the multi-objective Redundancy Allocation Problem for series–parallel systems. The work in [7] describes and demonstrates two methods to intelligently reduce the size of the Pareto set. The first method is a pseudo-ranking scheme that helps the decision maker select solutions that reflect his/her objective function priorities. In the second approach, the authors used data mining clustering techniques to group the data by using the k-means algorithm to find clusters of similar solutions. Ref. [9] presents a method that can be used to design an ad hoc network topology optimized for higher reliability. Ref. [11] presents an algorithm based on a hybrid optimization approach (probabilistic solution discovery and Monte Carlo simulation) to solving problems related to minimization of the network design cost, subject

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to a known constraint on all-terminal reliability. Ref. [15] addresses the problem of determining the optimal network design within a multi-objective search based on an effective coupling of genetic algorithms and Monte Carlo simulation. In turn, Ref. [16] has solved the reliability optimization problem by using a heuristic approach based on a quantized Hopfield network. Finally, Ref. [17] presents an application of ant system in a reliability optimization problem for a series system with multiple-choice constraints to maximize the system reliability to the system budget.

Note that none of these references considered the business metrics formally. Instead, they deal with business metrics as constraints to designs based on technical metrics. The main contribution of this work in comparison with the previous works is related to the usage of business metrics integrated with technical metrics in the formal modeling. We evaluate and compare alternative infrastructure designs considering not only technical metrics, but specially business metrics, in a formal way. It extends our preliminary research work presented in [1–3], consolidating and generalizing their results, as well as proposing new analytical models for supporting optimization of converged networks design, aimed at business oriented metrics. In addition, a new methodology is also adopted to reduce the complexity of infrastructure design as well as improving the relationship between infrastructure and business aspects. The obtained results show that the proposed approach provides quasi-optimal infrastructure design that improves the business aspects such as infrastructure revenues, costs and profits. Furthermore, it provides the possibility of an objective comparison among different design solutions.

The rest of this paper is organized as follows. Section 2 describes the business-oriented and network infrastructure models. Section 3 explains the adopted methodology in order to select the quasi-optimal design considering the relationship between business and infrastructure aspects. Section 4 presents a case study where we apply our approach in a real converged network. Finally, Section 5 concludes the paper and introduces ideas for future research works.

## 2. Models

This section presents the models adopted for quantifying the network infrastructure performance and dependability based on business-oriented aspects.

### 2.1. Business-oriented models

This section presents a set of business metrics to support the optimization of infrastructure design.

*Infrastructure cost*: The next expression is based on the Calculating Infrastructure Cost [10]. In order to calculate the infrastructure cost, one needs a model considering the infrastructure resources of hardware and software. Each $l$-th component, such as a router, consists of a set of $n$ resources, such that $C_l = \{r_1, r_2, \ldots, r_n\}$. As an example, a router consists of two resources: hardware and operating system. In turn, each $k$-th component class, i.e., router class, switch class, consists of similar components, such that $CL_k = \{C_1, C_2, \ldots, C_l\}$. In turn, RC is the set of $k$ component classes, such that $\mathrm{RC} = \{CL_1, CL_2, \ldots, CL_k\}$. Each resource has a cost rate (cost per unit time) of $r_{\mathrm{k,l,n}}$. If each resource has a variable cost rate ($r_{\mathrm{k,l,n}}$):

$$ICost(t) = \int_0^t \left( \sum_{k=1}^{|RC|} \sum_{l=1}^{|CL_k|} \sum_{n=1}^{|C_l|} r_{k,l,n}(\tau) \right) \times d\tau \tag{1}$$

Now, a constant cost rate is assumed. Let $t$ be equal to $T$ (a constant time period, $t=T$). The cost of the infrastructure over the time period $T$ (typically 1 month or 1 year[1]) can be calculated as the sum of individual cost for all components (see Eq. (2)). This work considers the constant cost rates:

$$ICost(T) = \left( \sum_{k=1}^{|RC|} \sum_{l=1}^{|CL_k|} \sum_{n=1}^{|C_l|} r_{k,l,n} \right) \times T \tag{2}$$

*Infrastructure revenues*: This study considered the calculation of revenues directly from the converged networks in a service provider perspective, through resource allocation to the customer. This model considers a customer and its services. A generalization to a greater number of customers is straightforward.

The proposed model calculates the revenues from each type of service that flows through the network. It considers features such as system availability ($A$), throughput ($thps$) and financial value ($fv$) of a service $j$. If a variable throughput is considered:

$$Rv(t, A, thps, fv) = \int_0^t \left( \sum_{j=1}^{k} A(\tau) \times thps_j(\tau) \times fv_j \right) d\tau \tag{3}$$

Now, the mean throughput and a steady-state availability are assumed. Let $t$ be equal to $T$ (a constant time period, $t=T$). The revenues of the infrastructure over the time period $T$ (typically 1 month or 1 year see footnote 1) can be calculated (see Eq. (4)). This work considers the mean throughput.

$$Rv(T, A, thps, fv) = \left( \sum_{j=1}^{k} A \times thps_j \times fv_j \right) \times T \tag{4}$$

- $thps$: mean throughput, in packets per second (pps);
- $thps(\tau)$: instantaneous throughput, in packets per second (pps);
- $A$: steady-state system availability in the time period;
- $A(\tau)$: instantaneous availability;
- $T$: time period;
- $fv$: financial value associated with a service, in \$/packet.

*Penalty*: The penalty is based on the system time outage and its cost, per $j$ service, is calculated according to the offered service level (see Eq. (5)) over a time period $T$ (typically 1 month or 1 year see footnote 1). Regarding function $I$, Eq. (6) shows its different values in accordance with the offered service level. Thresholds, regarding availability, should be defined for each service level ($th_n < th_{n-1} < \cdots < th_2 < th_1$).

As an example, considering that the calculated availability is greater than a threshold defined in a contract ($th_1$), there is no penalty and the value of function $I$, $I_1$, is zero.

$$P_j(T, A, I) = \begin{cases} 0 & \text{for } A \geq th_1 \\ T \times I_2 \times (1-A) & \text{for } th_2 \leq A < th_1 \\ \vdots & \vdots \\ T \times I_n \times (1-A) & \text{for } th_n \leq A < th_{n-1} \end{cases} \tag{5}$$

$$I(A) = \begin{cases} I_1 & \text{for } A \geq th_1 \\ I_2 & \text{for } th_2 \leq A < th_1 \\ \vdots & \vdots \\ I_n & \text{for } th_n \leq A < th_{n-1} \end{cases} \tag{6}$$

The total cost of the penalty over a time period $T$ can be calculated as the sum of individual cost of penalties for each service $j$ (see Eq. (7)):

$$P_T(T, A, I) = \sum_{j=1}^{k} P_j \tag{7}$$

[1] Its value, in month/year, must be converted to the appropriate value in hours or seconds.